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Research article

Mechanisms for Triceps Surae Injury in High Performance Front Row Rugby Union Players: A Kinematic Analysis of Scrummaging Drills

Carol A. Flavell [1]✉, Mark G. L. Sayers [2]✉, Susan J. Gordon [3] and James B. Lee [4]
[1] School of Public Health, Tropical Medicine & Rehabilitation Sciences, James Cook University, Townsville, QLD, Australia; [2] School of Health and Sport Sciences, University of the Sunshine Coast, Maroochydore, 4556, QLD, Australia; [3] School of Public Health, Tropical Medicine and Rehabilitation Sciences, James Cook University, Townsville, QLD, Australia; [4] Keio University, Fujisawa, Kanagawa, Japan

Abstract
The front row of a rugby union scrum consists of three players. The loose head prop, hooker and tight head prop. The objective of this study was to determine if known biomechanical risk factors for triceps surae muscle injury are exhibited in the lower limb of front row players during contested scrummaging. Eleven high performance front row rugby union players were landmarked bilaterally at the posterior superior iliac spine (PSIS), greater trochanter, lateral femoral epicondyle, midline of the calcaneus above the plantar aspect of the heel, midline lower leg 5cm and 20cm proximal to the lateral malleolus, at the axis of subtalar joint, lateral malleolus, and head of the fifth metatarsal. Players were video recorded during a series of 2 on 1 live scrummaging drills. Biomechanical three dimensional analysis identified large angular displacements, and increased peak velocities and accelerations at the ankle joint during attacking scrummaging drill techniques when in the stance phase of gait. This places the triceps surae as increased risk of injury and provides valuable information for training staff regarding injury prevention and scrum training practices for front row players.

Key words: Rugby, athletes, kinematics, injuries.

Introduction

Rugby union (rugby) is a sport with frequent body contact between players, and a high incidence of injury (Brooks and Kemp, 2008; Collins et al., 2008; Fuller et al., 2007; Holtzhausen et al., 2006). The contested scrum is a key mechanism for restarting the game. Under normal circumstances, eight players from each team contest the scrum. These players are organized into three rows in a scrum formation: a front row (three players), a second row (two players) and a back row (three players). There are approximately 19 scrums per game in international rugby (IRB, 2007; 2011), and many teams use the scrum to establish dominance over their opposition and to initiate their attacking plays. A front row player's position is in the middle of a scrum between their own second row and the front row of the opposing team. The front row players are exposed to large, multi-directional passive forces, while their feet remain in contact with the ground (Milburn, 1990; Quarrie and Wilson, 2000; Wu et al., 2007). Forces upon the front row fluctuate during the scrum, with the tight head prop transmitting the greatest force at engagement, but the loose head prop more of the forward force (60%) following engagement (Milburn, 1990). Despite the decreasing number of scrums per international match the number of collapses and resets was significantly higher at the highest international match level during the 2011 Rugby Union World Cup (IRB, 2007; 2011). Previous studies have reported that the risk and propensity for injury during scrummaging is high (Fuller et al., 2007) and that strong associations between scrummaging, playing position and triceps surae (TS) muscle and Achilles tendon injuries exist (Brooks et al., 2005; Fuller et al., 2007). Additionally, injuries arising from scrummaging are of greater severity than injuries arising from other activities during rugby play (Brooks et al., 2005; Fuller et al., 2007).

The TS comprises three superficial calf muscles; gastrocnemius, soleus and plantaris. The gastrocnemius and soleus muscles form a three sectioned muscular structure and combine as the tendo calcaneus (TA). The gastrocnemius is biarticular, crossing both the knee and ankle joint, whereas soleus exerts its affect across the ankle joint only. It is active concentrically during the 'push off' phase of lower leg function and the nature of the gastrocnemius' biarticular anatomy allows power and efficiency during explosive activities such as running and jumping. Research in other sports such as tennis and cricket has identified that injury to the TS occurred commonly with full extension of the knee combined with plantar flexion of the ankle during weight bearing activities in the 'push off' phase of gait (Orchard et al., 2002). This position leads to overload and subsequent trauma to the TS (Froimson, 1969) which is particularly relevant when considering the high speed, force and repeated direction changes exhibited by rugby players.

Previous rugby scrummaging research has been conducted with players against scrummaging machines in a motion laboratory (Milburn, 1993; Quarrie and Wilson, 2000; Sayers, 2008; Wu et al., 2007), or have been machine contested scrums conducted on synthetic grass surfaces (Quarrie and Wilson, 2000; Wu et al., 2007). Importantly, this research identified that during machine based studies, a more extended lower limb joint position was adopted by all subjects while scrummaging, with increased hip and knee extension and increased plantar flexion of the ankle observed (Quarrie and Wilson, 2000; Wu et al., 2007). This position was adopted in order to generate greater force and to resist angular displacement at the joints (Quarrie and Wilson, 2000; Wu et al., 2007).

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However this position will place the TS at risk of injury.

While this information is useful it has been acknowledged that the rigidity of scrummaging machines does not replicate the multidirectional and fluctuating opposing forces experienced by players during live scrummaging (Milburn, 1990). Similarly, the use of synthetic grass surfaces in previous research does not replicate the typical under foot conditions of a grass surface (Ekstrand et al., 2006).

Accordingly, the objectives of this study were to use three dimensional kinematic analysis to determine the lower limb biomechanics of high performance front rowers on a grass field, wearing studded boots, during a number of 2 on 1 scrum drills. Additionally, lower limb kinematics were compared between attacking and defensive 2 on 1 scrum drill techniques and results from this scrum activity were compared to results of previous research conducted with scrum machines. It was hypothesized that lower limb kinematics would differ between the attacking and defensive scrum positions, and between the drill and machine scrummaging. Additionally, it was hypothesized that some scrummaging techniques would expose players to known biomechanical risk factors for TS injury.

Methods

Participants

Eleven male (age 23.3 ± 3.4 years; height 1.77 ± 0.15 m; body mass 110.8 ± 4.4 kg) front row rugby players with international competition experience were invited to participate in the study. Participants had no previous history of TS injury and were injury free at the time of testing. All participants were informed of the institutional ethically approved experimental procedures and written consent was obtained from them prior to data collection.

Experimental design

Participants performed a series of typical live scrum drills where two front rowers scrummaged against one opposing front rower (2 on 1). Participants were randomly assigned to, and rotated through all three positions during these 2 on 1 drills. This drill configuration was chosen to enable both sides of the players to be videoed while scrummaging. Cameras were positioned to collect data regarding the position of the hip, knee, ankle and subtalar joints during two scrum positions, one attacking and the other defensive (see Figure 1). The data was analyzed to determine body alignment, angular velocity, angular acceleration, and spatio-temporal gait measures. Results were compared to identify any differences between the attacking and defensive scrum positions.

Experimental procedures

The land marking protocol for participants was conducted as follows. Colored, 1 cm circumference adhesive markers, were placed bilaterally on each participant at the head of the 5th metatarsal, midline of calcaneus above plantar aspect of heel, superior posterior aspect of heel at axis of subtalar joint, midline lower leg 5 cm and 20 cm proximal to lateral malleolus, lateral malleolus, lateral femoral epicondyle, greater trochanter, and posterior superior iliac spine. This allowed data capture for three dimensional descriptions of the pelvis and lower extremities.

Four digital camcorders (NV-GS180GN, Panasonic 3CCD.Panasonic Corporation, Osaka Japan) operating at 50 Hz with a shutter speed of 1/3000 s were placed on tripods at a height of 2.5 m. This configuration gave combined frontal/sagittal views, and provided overhead views of the participants in a crouched scrummaging position (Figure 1).

Prior to data collection, calibration of the system was completed in a central position within the testing area using a calibration device with 16 known locations which replicated the anatomical landmarks. The device's dimensions were 1.0 m, 1.75 m, and 1.0 m for X, Y, and Z orthogonal coordinates with positive movement to the right, forward and vertically upwards respectively.

Experimental testing was conducted on a grass rugby field that was dry underfoot. Participants wore studded boots and warmed up for at least thirty minutes, after which each participant performed their usual scrummaging technique for 20 s and rotated through each scrum position in random order. Each drill consisted of two props, either a loose head or tight head, and one hooker in random position. Participants were requested to scrummage in their usual manner with maximum effort, but maintain a linear progression either directly forwards or backwards within the video analysis area of the rugby field. The participants were instructed that the 2 on 1 configuration was expected to result in 2 on 1 dominance which would represent normal defensive conditions for the single front rower in the scrum drill. Participants rested for 30 s between drills. Video capture of 22 scrummaging drills was completed in one session.

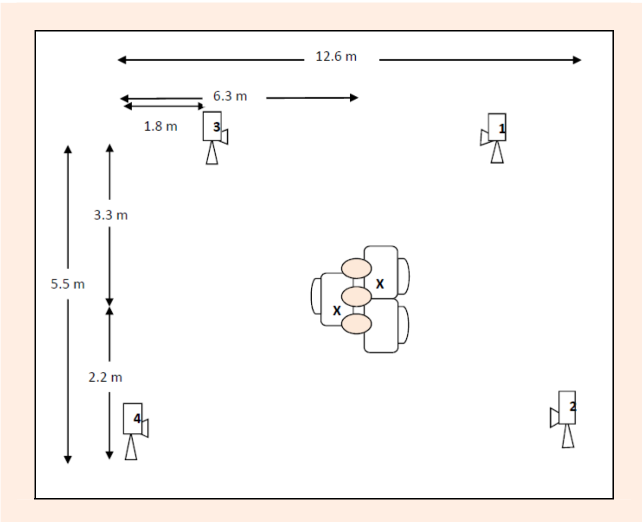

Figure 1. Representation of the experimental testing area (1, 2, 3 and 4 represent video camera locations, X denotes the participant positions from which data was collected).

Phase of scrummage

Phases of the scrummaging activity were defined as; (a) the point of engagement when initial body contact of the participants occurred, (b) boot ground contact defined as any point of contact with the ground that is made by any part of the participants right or left boot during the 20 s scrummaging activity. Stance and single stance phase of the scrummaging gait pattern were defined as the duration of time that a participant had either both or one boot in contact with the ground respectively.

Kinematic data

Anatomical landmarks were digitized using Ariel Performance Aanalysis System (APAS) software (Ariel Dynamics Inc. USA), and a three-dimensional model of the pelvis and lower limb was developed for each participant. Relative joint angular displacements were calculated for the subtalar, ankle, knee and hip (180° in full extension), along with angular velocities and accelerations. All spatial (m) and temporal (s) descriptors of gait were recorded. Step length was calculated from antero-posterior linear displacement of the head of the 5th metatarsal marker, between one toe strike and the contralateral toe strike. Step width was calculated from medio-lateral linear displacement of the head of the 5th metatarsal marker, between one toe strike and the subsequent ipsilateral toe strike. Ten additional frames were digitized either side of the scrummaging activity to allow for potential end points errors. Data from these additional frames was deleted after the smoothing process. The APAS software uses standard direct linear transformation (DLT) procedures to reconstruct 3D space from two-dimensional coordinates (Abdel-Aziz and Karara, 1971). This software has been shown to develop both accurate and reliable linear and angular kinematic data (Klein and Dehaven, 1995; Wilson et al., 1997). Transformed 3D data was smoothed using a digital low-pass Butterworth filter with a 5 Hz cut-off frequency.

Statistical analysis

Two conditions based on scrum drill type were defined; attacking (data from one of the two front rowers pushing forwards against one front rower), and defensive (data from the one front rower who was being pushed backwards by two front rowers). Means and standard deviations were calculated for both conditions. Independent t-tests were conducted to determine biomechanical differences between the scrum drill type conditions. Differences were considered statistically significant at $p < 0.05$, and effect sizes (ES) were used to provide a measure of the difference between the conditions (Cohen, 1988).

Results

Spatio temporal variables

Results showed no significant difference between the attacking and defensive scrum drill type conditions for spatio temporal variables of step width, length, and time.

Angular displacement variables

Throughout all phases of scrum drill type activity, the range of hip joint extension was greater during the defensive compared to the attacking scrum drill type condition. Breakdown analysis of various phases of the scrum drills showed significantly larger angular displacement at the hip joint throughout the scrum activity ($t(20) = -2.46$, $p = 0.023$, ES = -1.05), in stance ($t(20) = -2.45$, $p = 0.023$, ES = -1.05), single leg stance ($t(20) = -2.57$, $p = 0.018$, ES = 1.09) and initial single leg stance ($t(20) = -3.28$, $p = 0.004$, ES = -1.40) phases for the defensive condition. This was supported by large effect sizes for each of these variables.

During the defensive condition, results showed significantly larger angular displacement for the ankle at toe strike ($t(20) = -2.80$, $p = 0.011$, ES = -1.19) and the initial toe strike taken during the scrum drill ($t(20) = -2.71$, $p = 0.014$, ES = -1.15) compared to the attacking scrum position (Figure 2).

For the attacking condition, results showed significantly larger angular displacement of the ankle at toe off ($t(20) = 4.21$, $p < 0.001$, ES = 1.8), the ankle at initial toe off ($t(20) = 4.14$, $p < 0.001$, ES = 1.77), and the ankle at last toe off ($t(20) = 4.05$, $p = 0.001$, ES = 1.73). The knee at toe off ($t(20) = 2.20$, $p = 0.04$, ES = 0.94), the knee at initial toe off ($t(20) = 2.19$, $p = 0.04$, ES = 0.94),

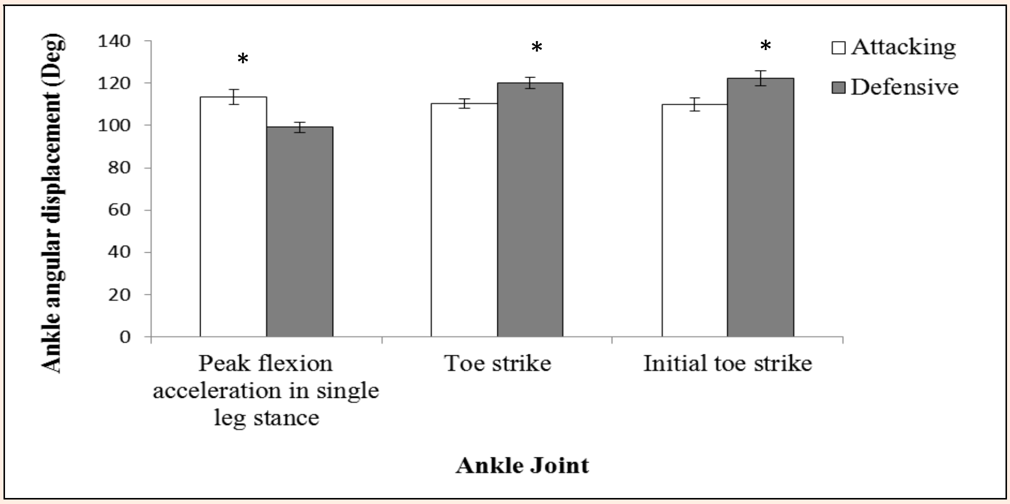

Figure 2. Angular displacement (Deg) of ankle joint at peak flexion acceleration, toe strike and initial toe strike for both scrum conditions. * Significant at $p < 0.05$.

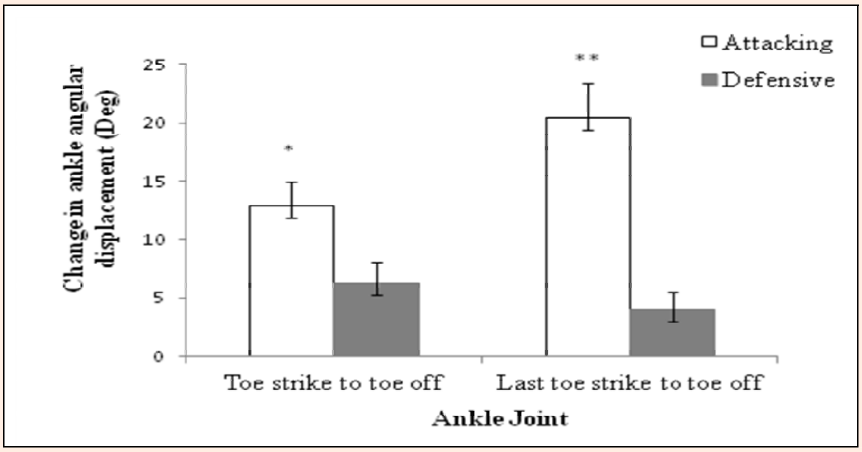

Figure 3. Change in angular displacement (Deg) from toe strike to toe off and last toe strike to toe off at ankle joint, for both scrum conditions. Significant at * $p < 0.05$, ** $p < 0.001$.

and the knee (t (20) = 2.49, p = 0.022, ES = 1.06) at last toe off.

Range of movement (ROM) was greater at the ankle and knee joint during weight bearing phases of the attacking than the defensive scrummaging condition. There were significantly larger changes in angular displacement at the ankle joint from toe strike to toe off (t (20) = 2.39, p = 0.027), compared to the defensive condition. This was supported by large effects size (ES = 1.02).

Similarly, significantly larger changes in angular displacement at the ankle joint from last toe strike to toe off were recorded in the attacking condition, with large effect sizes (t (20) = 5.04, $p < 0.001$, ES = 2.15), compared to the defensive condition (Figure 3). Results indicated also larger ankle joint angle at peak extension acceleration in stance phase supported by large effect size, under attacking condition (t (13.144) = 2.34, p = 0.036, ES = 1) compared to defensive conditions.

At the knee joint, significantly larger angular displacement at peak flexion acceleration in stance phase, occurred in the attacking condition than the defensive condition (t (20) = 2.76, p = 0.012, ES = 1.18). This indicates that when weight bearing during attacking scrummaging peak flexion acceleration of the knee joint occurred from a more extended position than during the defensive scrum position.

The attacking scrum condition resulted in significantly larger ankle joint angles at peak flexion acceleration when compared with the defensive condition in single leg stance phase (Figure 2). This was supported by large effect size (t (20) = 3.34, p = 0.003, ES = 1.42). The results indicate that during attacking scrummaging, when participants were in single leg stance, ankle joint peak flexion acceleration occurred at a more plantar flexed position than during defensive scrummaging. Significantly larger peak extension velocity in single leg stance phase was recorded at the hip (t (20) = 2.48, p = 0.022, ES = 1.06), and knee (t (18) = 4.41, $p < 0.001$, ES = 2.01) in the attacking compared to the defensive condition.

Comparison between scrum conditions showed that the attacking condition resulted in significantly larger peak extension (t (14.12) = 3.55, p = 0.003, ES = 1.51) and flexion (t (20) = -2.9, p = 0.009, ES = -1.24) accelerations at the ankle joint in single leg stance phase. Additionally, results indicated significantly larger peak extension acceleration at the knee joint in single leg stance phase (t (20) = 3.39, p = 0.003, ES = 1.44) during the attacking compared to the defensive condition. These results were supported by large effect sizes.

Discussion

The results of this study identified numerous significant differences in lower limb kinematics between the attacking and defensive scrum drill types. Large ranges of knee extension were combined with ipsilateral ankle joint plantar flexion in both scrum conditions. This occurred at toe strike in the defensive scrum and toe off in the attacking scrum.

Results from studies using scrum machines have reported greater force production related to more extended lower limb joint positions (Milburn, 1990; Quarrie and Wilson, 2000; Wu et al., 2007). The reported angular displacements from these studies highlighted that while pushing against a machine, players adopted greater extension at the hip and knee combined with ankle plantar flexion (Quarrie and Wilson, 2000; Wu et al., 2007). This confirms our anecdotal observations of scrummaging and those of other informed observers. For example, in an attacking scrum, players are advancing forwards by generating forces greater than the opposing scrum. Accordingly, front row players are required to maintain foot position until the upper body is well in front of their base of support resulting in greater ankle plantar flexion. This pattern mimics the final push off phase of jumping and other explosive activities previously documented (Orchard, 2002). We acknowledge that the 2 on 1 drills we conducted were unlikely to generate similar forces compared to a full machine based scrum drill, however our study did not measure forces, and although a 3 on 2 scrum configuration may have produced more realistic forces, it would have hindered effective video capture. Therefore the findings of our study supported the hypothesis, that front rowers exhibit biomechanical patterns, which have been associated with TS injury in other sports (Orchard et al., 2002).

Significant differences at the ankle at toe strike and initial toe strike, knee and ankle at toe off, initial toe off, and last toe off in the attacking drills combined with greater knee joint angles were found. This is consistent with previous studies regarding the relationship of knee joint angle with maximum plantar flexion force production of the TS (Signorile et al., 2002). During scrummaging, the extended lower limb at toe strike will be under extreme load. In this situation the plantar flexed ankle joint is resisting passive dorsi flexion as stance phase begins. In summary, at toe strike, particularly during the defensive drills the TS must produce a strong eccentric contraction to resist the impact of the foot with the ground. The pattern of larger ankle and knee joint angles combined with forceful TS contraction reproduces a previously documented risk position for TS injury (Orchard, 2002). This indicates that plantar flexion at toe off while attacking, and at toe strike while defending are key phases of the scrum, which may predispose these players to increased risk for TS injuries.

The results of this research indicated also significant changes in ankle angular displacement from toe strike to toe off during the attacking scrum. These results identify that the degree of change from dorsi flexion to plantar flexion was greater during the attacking scrum than the degree of plantar flexion to dorsi flexion during the defensive scrum. In summary, a greater range of movement occurred at the ankle joint during the stance phase of the attacking scrum drills. This is the first study that the authors are aware of that has identified this biomechanical pattern. This finding highlights a potential risk factor for the TS injury because the lower limb is reaching the final stage of push off immediately after a large change in angular displacement at the ankle joint (Orchard et al., 2002; Kawakami et al., 1998).

Results for peak extension velocities at the knee, and hip joint during single leg stance phase were significantly greater during the attacking scrum drills. No previous studies have reported angular velocity or acceleration. During scrummaging it is a necessity for toe off to occur as soon as possible after a contralateral toe strike in order to drive forwards in the attacking scrum. This means that greater velocity must be generated over the single leg stance phase prior to ipsilateral toe off. Such patterns would be unlikely during defensive scrums due to backward player movement where flexion of the lower limb is the likely pattern. Results for knee peak extension velocity may be explained by the need to bring about a faster rate of knee extension initially after toe strike during defensive drills. This may be to stabilize the knee joint in its closed packed position of full extension. Stabilizing the knee in this way enables maximum force to be generated by the gastrocnemius. This assists the player to resist the push of the opposing scrum. In so doing, the player can delay backward movement and challenge the existing scrum behavior. During phases of single leg weight bearing, the ankle, knee and hip produced greater acceleration during attacking drills. Greater accelerations combined with the greater ankle and knee joint displacement reported from this research may be additional risk factors for TS injury.

Conclusion

A 2 on 1 scrum drill provides better dynamic variables typically seen in a scrum than when using a machine. This study identified that props and hookers exhibited patterns of single leg weight bearing, combined with greater ankle plantar flexion and knee extension at toe off during attacking scrummaging drills. Additionally our study showed greater changes in ankle ROM from toe strike to toe off during attacking scrum drills. These biomechanical factors place TS at greater risk of injury due to muscle overload.

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Key points

- Front rowers exhibited patterns of single leg weight bearing, in a position of greater ankle plantar flexion and knee extension at toe off during scrummaging, which is a risk position for TS injury.
- Front rowers also exhibited greater acceleration at the ankle, knee, and hip joints, and greater changes in ankle ROM from toe strike to toe off during attacking scrum drills.
- These reported accelerations and joint displacements may be risk factors for TS injury, as the ankle is accelerating into plantar flexion at final push off and the muscle is shortening from an elongated state.

AUTHORS BIOGRAPHY

Carol A. FLAVELL

Employment

Lecturer in Physiotherapy, School of Public Health, Tropical Medicine & Rehabilitation Sciences, James Cook University, Douglas Campus, Townsville, Australia.

Degree

MSc, GDip Phty

Research interests

Muscle measurement with Real Time Ultrasound. Chronic low back pain. Motion analysis of movement dysfunction.
Validation of physiotherapy objective measurement tools.

E-mail: carol.flavell@jcu.edu.au

Mark G. L. SAYERS

Employment

Senior Lecturer in Sports Biomechanics, School of Health and Sport Science, University of the Sunshine Coast, Australia.

Degrees

Ph.D, M.App.Sci., B.App.Sci.

Research interests

Sports biomechanics, analysis of the key skills from each of the main football codes

E-mail: msayers@usc.edu.au

Susan J. GORDON

Employment

Associate Professor of Physiotherapy, School of Public Health, Tropical Medicine and Rehabilitation Sciences, James Cook University, Townsville, Australia.

Degree

Ph.D, B.App.Sc (Physio), G.C.Tertiary Education

Research interests

Musculoskeletal and lymphatic systems

E-mail: susan.gordon2@jcu.edu.au

James B. LEE

Positions

Japan Society for the Promotion of Science Research Fellow, Graduate School of Media and Governance, Keio University, Japan.
Research Fellow, Centre for Wireless Monitoring and Applications, Griffith University, Australia.

Degree

PhD, BSc(Hons).

Research interests

Human movement assessment using microtechnologies.

E-mail: jim@qsportstechnology.com

✉ **Carol A Flavell**
School of Public Health, Tropical Medicine & Rehabilitation Sciences, James Cook University, Townsville, 4811, QLD, Australia